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INVESTIGATION OF SCHOTTKY BARRIER ON GaAs AND InP USING A MULTI-DISCIPLINED APPROACH

Dr. Nathan Newman*
Professor William E. Spicer
Al Green

Stanford Electronics Laboratories
McCullough Building, Room 238
Stanford, CA 94305-4055

* Lawrence Berkeley Laboratory, 62-203
University of California, Berkeley, CA 94720

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Professor William E. Spicer
Stanford Electronics Laboratories
Stanford University
Stanford, CA 94305-4055

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A. Defect and Schottky Barriers

A major development this year was the Advanced Unified Defect Model (AUDM). This focus on the As_{Ga} and the Ga_{As} antisites as the key defect which can govern the electronic properties at GaAs/metal as well as other GaAs interfaces. One importance of this is that it provides a framework through which the interfacial chemistry can be related to changes in Schottky barrier height. Details of the AUDM and its development are given in paper #6 on our list of publications. A copy is attached to this report.

As Figure 1 describes, the Fermi level position will be set by the relative number of As_{Ga} and Ga_{As} antisites. Because of the excess As and LEC GaAs, the As_{Ga} antisites usually dominate when LEC crystals are used. Thus the Fermi level is pinning near mid-gap. If an interface reaction produces excess As, the Fermi level, E_f, moves toward the CVM; if excess Ga E_f moves toward the VBM. As can be seen from the Figure, good agreement is obtained with the careful experimental data generated under this contract in annealing experiments. However, it is important that this work be expanded to other metals.

Oxides or other foreign layers at the interface complicate matters. However, it appears that the model appears even in these cases. The potential significance of this model goes far beyond the annealing experiments listed above. For example, it suggests that interfacial behavior may depend on the amount of As in the As grown crystals. Thus, we are initiating work on LEC crystals grown less As rich. (See papers 1, 6, and 7 on Publication list).

B. Leakage Paths at the Perimeter of Schottky Barriers

A yield and reliability problem for GaAs microwave diodes has been emitter-gate leakage. We have investigated the leakage at the perimeter of Au/GaAs Schottky barriers and have made a strong correlation with formation and movements of thin Au fingers or islands at the perimeter of the Au dot. Working strongly with our collaborators at Berkeley and elsewhere, we have gained a large amount of information concerning the morphology and chemistry taking place. A paper on this was presented at the World Materials Congress, Chicago on September 28-30, 1988. It appears that the leakage is due to a recombination path at the edge of these features. If the features are covered by a thick well defined Au overlayer, the leakage disappears. Work is continuing. (See paper 2 on Publication list).

C. Aging and Instability of Schottky Barriers

In order to set a base line and gain fundamental understanding, our first objective was to understand the ideal Schottky barriers in which no oxide or other foreign material was present at the interface. Considerable effort was expended this year in studying such "contaminated" Schottky barriers. Here the collaboration with our colleagues at U.C. Berkeley was quite important. This work is particularly important because practical Schottky barriers usually have contaminated interfaces. Thus the present work helps extend our fundamentals into more practical regimes.

One new area of study involves electrically stressing the diode by applying reverse bias for given periods of time and then measuring the changes in barrier height. Little effect was found if contamination was not present. Even with contamination present, Pd and Cr show negligible change with current stressing. The effects are increasingly larger for Al, Au, and Ag in that order. TEM studies find relatively large movement of Ag for

Ag/GaAs diodes due to the stressing. In fact voids are formed in the Ag at the interface (See # 3, 4, and 5 on the publication list).

D. Experimental and Theoretical Studies of Electron Transport Over Schottky Barriers.

Considerable effort has been spent in developing the techniques necessary to fundamentally study transport across Schottky barriers. One expenditure of time has been in working out computer programs and theoretical formalization of this problem. This has been difficult because the theoretical principal, Mark van Schilfgaarde has been located at the Max Planck Institute in Stuttgart, Germany for the last year. Mark will return to SRI this fall and things should come together. The other key part of this program is a experimental apparatus to allow electrical measurements to be performed at very low temperatures. This will be described in the next section

E. Building a New Apparatus for Forming and Measuring Ideal Schottky Diodes with Liquid He Cooling Capabilities

In order to facilitate this program and to make possible *in situ* measurements of Schottky Diodes at Low Temperature (Liquid He) after formation in UHV, we have devoted a major effort in the last year on the design, fabrication and testing of a major piece of equipment. This combines the capability of forming Schottky diodes with atomically clean interfaces and the ability to cool and measure these diodes at the very low temperature without breaking vacuum. The availability of this will open a number of new areas of research.

A sketch of the apparatus is given in Figure 2. Table 1 gives a summary of the low temperature operating characteristics of the apparatus. Both liquid nitrogen and liquid He operations are indicated. The sample temperatures given are those measured near the center of a 2 cm GaAs single crystal with one end mounted on the apparatus.

Our next step will be to attempt diode measurements on samples cooled with liquid He. After such measurement, we will move on to cleaving crystals (to form atomically

clean surfaces) and diode formation and measurements *in situ*. Bake out facilities are also being built to insure UHV.

F. Summary of plans for the next 18 months of this contract

Work described above will be continued to completion. However, the largest emphasis will be placed on taking advantage of the new low temperature apparatus and, in particular, of making the planned transport measurement. We are looking forward to collaboration with Mark van Schilfgaarde in this regard.

Publications

1. Mechanism for annealing-induced changes in the electrical characteristics of Al/GaAs and Al/.InP Schottky contacts, N. Newman, W. E. Spicer, and E. R. Weber, J. Vac. Sci. Tech. **B 5** (1987) 1020.

2. A Chemical and structural investigation of Schottky and ohmic Au/GaAs contacts, D. Coulman, N. Newman, G. A. Reid, A. Liliental-Weber, E. R. Weber, W. E. Spicer, J. Vac. Sci. Technol **A 5** (1987) 1521-1525.

3. Aging of Schottky diodes formed on air-exposed and atomically clean GaAs surfaces; An electrical study, A. Miret, N. Newman, E. R. Weber, Z. Liliental-Weber and J. Washburn, W. E. Spicer, J. Appl. Phys. **63** (1988) 2006-2010.

4. Schottky barrier instabilities due to contamination, N. Newman, Z. Liliental-Weber, E. R. Weber, J. Washburn, and W. E. Spicer, Appl. Phys. Lett. **53** (1988) 145-147.

5. The Influence of Current Stressing on the Structure of Ag Contacts to GaAs, Z. Liliental-Weber, A. Miret-Goutier, N. Newman, C. Jou, W. E. Spicer, J. Washburn, and E. R. Weber, Mat. Res. Soc. Symp. Proc. **102** (1988) 241-244.

6.. The Advanced Unified Defect Model and Its Applications, W. E. Spicer, T. Kendelewicz, N. Newman, R. Cao, C. McCants, R. Miyano, I. Lindau, and E. R. Weber, Applied Surface Science **32**, No. 4, August (1988).

7. Disruption, Metallization, and Electrical Properties of Metal GaAs and InP Semiconductor Interfaces, W. E. Spicer, R. Cao, K. Miyano, C. McCants, T. T. Chiang, C. J. Spindt, N. Newman, T. Kendelewicz, I. Lindau, E. Weber and Z. Liliental-Weber, presented at Nato Advanced Research Workshop on Metallization and Metal-Semiconductor Interfaces, Garching bei Munchen, Germany, August, 1988, To be published in the proceedings, by Plenum Publ. Corp. N.Y.

Table I. Summary of Operations and Characteristics of the Low Temperature Manipulator

The low temperature manipulator cools samples to near liquid helium temperatures where current-voltage measurements are made. Samples are in thermal contact with a small liquid helium reservoir which is surrounded by a liquid nitrogen shroud. The whole system is operated in UHV. The procedure is to first cool the liquid helium reservoir to liquid nitrogen temperatures, after the helium reservoir has been emptied, liquid helium is put in. Liquid nitrogen is kept in the outer nitrogen shroud throughout the experiment. The following figures characterize the cooling of the manipulator. (The sample temperatures are those near the middle of a 2 cm long GaAs crystal mounted in the apparatus.)

ROOM TEMP -> LIQUID NITROGEN TEMP.

approximate time (after liquid accumulation) = 2 minutes

final temperature at liquid helium reservoir = 77K

final temperature at sample = 77K

consumption rate : negligible

LIQUID NITROGEN TEMP -> LIQUID HELIUM TEMP.

approximate time (after liquid accumulation) = 1 minute

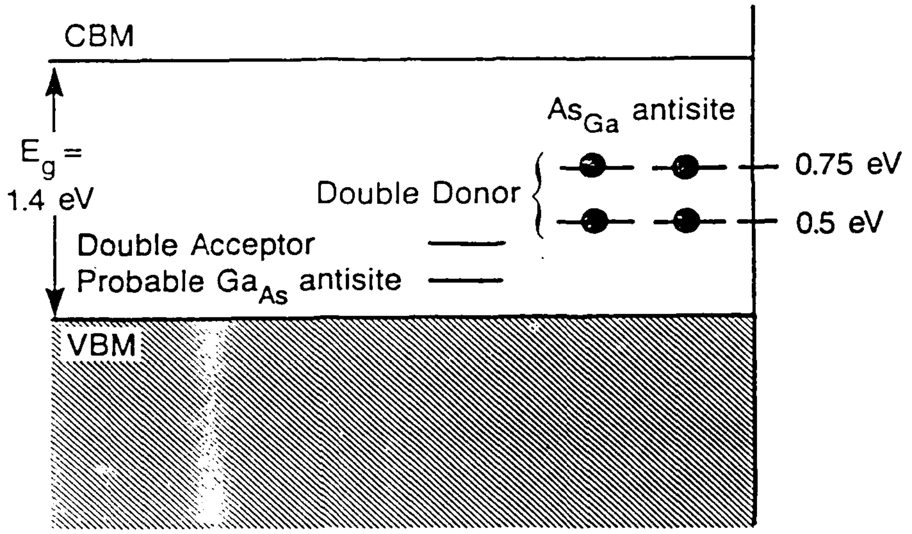
final temperature at liquid helium reservoir = 4.2K

final temperature at sample = 7K *

consumption rate ~ 1 liter/hour

(* with better thermal contact between the reservoir and the sample, we hope to lower this temperature.

Figure 1



ADVANCED UNIFIED DEFECT MODEL

- Position of E_{fi} depends on: Antisite Ratio $\frac{N(As_{Ga})}{N(Ga_{As})}$
  - •• If $\frac{N(As_{Ga})}{N(Ga_{As})}$ increases (i.e. As excess),
    E_{fi} moves toward CBM and ϕ_n decreases
  - •• If $\frac{N(As_{Ga})}{N(Ga_{As})}$ decreases (i.e. Ga excess)
    E_{fi} moves away from VBM and ϕ_n increases

Reaction	Products	Change in $\phi_B(n)$ Predicted	Observed Change in ϕ_B
Au + GaAs	GaAu + Au	decrease	- 0.1
Al + GaAs	AlAs + Ga	increase	+ 0.1
Ti + GaAS	TiAs + Ga	increase	+ 0.1
Ag + GaAs	none	none	none

- Systematics of ϕ_B changes due to chemistry
- From chemistry can predict ϕ_B direction as changes on thermal annealing
- Oxides or other foreign layers at interface complicate matters but basic results found to be the same
- AUDM gives first model connecting interfacial chemistry and barrier height

LOW TEMPERATURE APPARATUS

1. Electrical Feedthroughs
2. Bellows
3. X,Y,Z Manipulator
4. Experimental equipment ports
5. View port
6. Diodes Fabrication and measurement area
7. Pumping station (not shown)

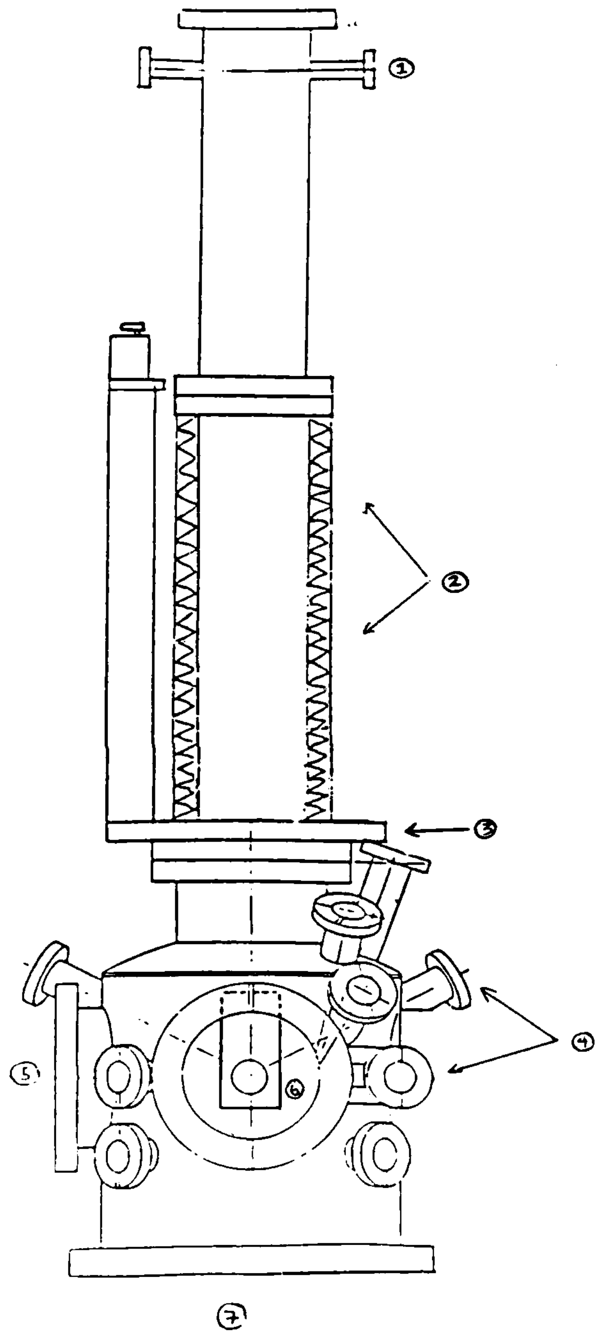


Figure 2. The new liquid He cooled fabrication and measurement apparatus. The height of the section shown is 4'. With pumps and liquid He transfer sections, the total height is 8'.